FINAL REPORT

SOIL IMPROVEMENT AND CARBON SEQUESTRATION WITH FORAGES

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Soil Improvement and Carbon Sequestration With Forages

A Three Year Study in East-Central and North-East Saskatchewan

Final Report

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Summary

A three year study (1998 – 2000) was conducted in the east-central and north-eastern agricultural regions of Saskatchewan to determine how conversion of marginal annually cropped land to native and introduced forage species (mainly grasses) has influenced the amounts and quality of organic matter in the soil after five to twelve years. Comparisons were made using several paired matches of annually cultivated versus forage seed-downs in Ducks Unlimited conservation areas.

This study revealed that conversion of annually cultivated or disturbed land to forages has a positive impact on the quantity and quality of surface soil organic matter in the Black and Gray soil zones after five to twelve years. Mean amounts of soil organic carbon (0-15 cm) from six comparisons in the Dark Brown – Thin Black transition area near Meacham and Dana, Sk. was 59.4 Tonnes C / ha in the grass seed-down treatments and 52.6 Tonnes C / ha in the cultivated treatments. In the Black – Gray transition area near Gronlid and Pleasantdale, Sk., the mean soil organic carbon amount in six comparisons was 44.5 Tonnes C / ha in the seed-down while that in the cultivated was 22.5 Tonnes C / ha. Apparent carbon gains were higher in the more moist soil climatic zones and were greatest where the cultivated equivalent involved a high frequency of tillage and fallow and where significant topsoil had been removed by erosion (knolls) and excavation. Based on this study, net carbon sequestration or gain rates were estimated to range from 0.6 to 1.2 Tonnes C / ha / yr over an approximate ten year time interval. Labile, easily decomposed organic matter was higher in seed-downs than cultivated equivalents. Higher release rates of available nitrogen were observed in forage seed-downs, especially those containing a legume such as alfalfa, indicating an improvement in nitrogen fertility with long-term forage seed-down.

Technical Report

Note: Specific details of the experimental work completed over the last three years are provided in the previous five progress reports and in the MSc thesis by Mr. Fred Mensah which is included as an appendix to this report. Therefore, this section is intended to provide an overview of the results and significance of the work completed.

Background and Objectives

The objective of the work was to determine how conversion of annually cultivated marginal lands to perennial forage seed-down influences soil organic matter amounts, composition and quality after five to ten years in the Black and Gray soil zones as well as to identify how the land management, soil type and slope position influence carbon sequestration in the system. Through the work of a graduate student, Mr. Fred Mensah, in the Department of Soil Science, University of Saskatchewan, we were able to determine rates of carbon gain, forms of carbon accumulated, and impact on nutrient release as influenced by seed-down of forage grasses and legumes on marginal lands in two study areas in east-central and north-eastern Saskatchewan. The influence of slope position and vegetation were also determined.

Project Activities and Achievements

There is increased interest in Saskatchewan in the conversion of marginal annually cropped lands to permanent forage cover. Driving forces for this conversion include low commodity prices and high transportation costs for grains, especially in eastern and north-eastern regions of Saskatchewan, concerns over deterioration of soil quality in annually cropped marginal (hilly, sandy) soils, as well as programs intended to encourage conversion to forages. Important considerations in such a change in land use are the potential effects on soil organic matter quality and quantity. Increases in soil organic matter (carbon) provide a benefit to the land-owner in improved soil quality and also a benefit to society as the soil acts as a sink for carbon dioxide.

Research Study Sites: The sites for this study were located near Meacham and Dana, SK in the Dark Brown- Thin Black transition zone, and near Gronlid and Pleasantdale, SK in the Black – Gray transition zone. Where possible, catenas were selected for side-by-side comparison of annually cropped versus grass seed-down. The study areas were located in Ducks Unlimited conservation areas which enabled documentation of the site history as to seeded species and management history since establishment of the seed-down. The majority of comparisons were between annually cultivated and five to twelve years after seed-down to a mixture of native and introduced species, including wheat grasses, brome grasses, needle grasses and legumes such as alfalfa. The cropping systems compared varied in rotation and tillage system from cereal-fallow conventional tillage to multi-crop direct seeded systems.

Methodology: Soil cores were taken at random from a 25 m^2 sampling area at each slope position: shoulder, backslope, footslope, wetland fringe in the cultivated and forage seed-down catenas. The cores were sectioned into 0-5 cm, 5-10 cm and 10-15 cm depth increments and air-dried for bulk density determination. Soil organic carbon (SOC) and light fraction organic carbon (LFOC) mass was determined in each sample using a carbon analyzer and stable carbon isotope abundance was determined by mass spectrometry. Supply rates of available phosphorus and nitrogen from mineralization of organic matter were measured in an incubation of intact cores over a four week period. Microbial activity and respiration was assessed using an incubation and measurement of carbon dioxide.

Results and Discussion: Individual comparisons of soil organic carbon in annually cultivated versus grass seed-down pairs at individual slope positions usually, but not always, revealed significantly higher organic carbon mass in the top 15cm of the seed-down than in the cultivated comparable. The average amounts of soil organic carbon (0-15 cm) across the landscapes for the comparisons in each study region are shown in Table 1.

Table 1. Average amounts of soil organic carbon (0-15cm) in forage seed-down and cultivated comparisons in the three study regions.

Study Area	Seed-down	Cultivated
	----------Tonnes C per hectare ----------	
Meacham	59.4 ± 4.1	52.6 ± 2.6
Dana	43.1 ± 2.5	36.1 ± 1.9
Gronlid	44.5 ± 4.5	25.5 ± 3.1

The net rate of soil organic carbon gain (0-15cm) in the grass seed-downs in the Meacham study area was estimated to be ~ 0.8 Tonnes C / ha / yr, based on the soil organic carbon mass difference between the treatments and the average age of the seed-downs. The combined analysis using the six comparisons in the Dana area revealed a net rate of carbon gain of ~ 0.9 Tonnes C / ha / yr. For comparisons in the Gronlid-Pleasantdale study area, the net C gain rate was estimated to range from ~ 1.5 to 1.9 Tonnes C / ha / yr, which may be an overestimate due to to uncertainty about the age of some treatments and possible non-equivalent matches. However, higher rates of carbon gain in more moist soil-climatic zones are expected.

In the landscapes at these sites, shoulder positions and eroded areas were most responsive to carbon gains from seed-down to perennial grasses. The soil carbon accumulation by perennial grasses is attributed to high allocation of carbon below-ground, greater transpiration leading to drier soils and lower decomposition rates, formation of stable aggregates and the absence of cultivation. Mixed grasses in seed-down are better able to use subsoil moisture due to species having extensive rooting habits as well as fine roots. Apparent carbon gains were more pronounced where the cultivated equivalent involved a short rotation (i.e. cereal-fallow) and a high degree of tillage. Overall, the estimates of net gain rates of soil organic carbon in this study (~0.6 to 1.2 Tonnes C / ha / yr) over an approximate 10 year time interval, are consistent with estimates made in the U.S. for the Conservation Reserve Program studies and concur with established estimates for seeded grasslands over this period of time.

The light fraction organic carbon mass and proportion of soil organic carbon comprised of light fraction organic carbon (%LFOC) were higher in the surface (0-5cm) of the grass seed-downs than in the cultivated treatments. Data for %LFOC in three comparisons at the Meacham study area is shown in Table 2

Table 2. Mean light fraction proportions of SOC (% LFOC) in the 0-5 cm depth in shoulder positions of three comparisons at the Meacham study area.

Site	*Seed-down*	*Cultivated*
	----------% LFOC in SOC--------	
Hanuschuk	15.8	5.5
LeBlanc	14.3	9.9
Sopatyk	21.1	11.8

The light fraction organic carbon is considered to represent the recent, easily decomposed portion of soil organic matter, which is derived from recent residue inputs. A high % LFOC indicates a system that is more rapidly gaining soil organic carbon, as indicated in the seed-down treatments.

The stable carbon isotope abundance measurements revealed a contribution to soil organic carbon of both cool season (C_3) and warm season (C_4) grasses in the seed-down treatments. The cool season grass isotope signature was more pronounced in foot slopes and wetland fringes, where cooler, moister conditions would favor the cool season species. The warm season (C_4) grass signature such as from blue grama grass was most evident on disturbed sites where the native soil organic matter was removed by erosion and excavation and C_4) species were present in the colonizing vegetation.

As expected, highly eroded and disturbed sites with low soil organic matter showed the lowest microbial activity and respiration. Seed-down of these sites to grasses was associated with greater microbial activity as indicated by higher respiration rates (evolution of carbon dioxide) in an incubation study. Native pasture soils had high microbial activity and respiration compared to other treatments.

The supply rates of nitrate and phosphate released over time to the PRS^{TM} resin membrane probes were useful as indicators of nutrient availability and mineralization potential as affected by the change in land-use. Higher initial nitrate and phosphate supply rates were observed in many cultivated treatments than in their paired grass seed-down equivalents, likely due to residual fertilizer nitrogen and phosphorus. However, increases in nitrate supply rates in the seed-downs over time indicate higher N mineralization potential in the seed-down treatments than the cultivated equivalents. Seed-downs that included a forage legume like alfalfa showed consistent and significantly higher N supply rates than pure grass seed-downs. However, alfalfa managements often showed low P supply, likely due to more P removed in alfalfa harvest. As such, low P availability may be limiting carbon accumulation potential in the systems. In this study, all of the forage seed-downs in the comparisons were unfertilized. It is anticipated that fertilization of forage stands would not only improve above-ground production of harvestable

economic product, but would also contribute to higher rates of soil organic matter accumulation and greater carbon sequestration.

Conclusions: Seed-down of grasses and forage legumes appears to have a positive effect on surface soil organic carbon stores in marginal soils in east-central and north-eastern Saskatchewan. Based on results of this project, which looked at seed-downs in place for five to twelve years, carbon sequestration rates are estimated to be ~ 0.6 to 1.2 Tonnes carbon / ha / yr. Indicators of soil quality were generally positively influenced by the forage seed-down. Limitations in this study include uncertainty in validity of the assumption that all paired comparisons were representative matches, equivalent in soil carbon content prior to the seed-down and at steady state. As well, this study only looked at carbon differences in the top 15 cm of the soil profile. As an outcome of this project, future research work will examine soil organic carbon stored at greater depths in the soil profile, especially in low slopes and the wetland fringe. The effect of conversion to forages will also be studied in Brown and Dark Brown soils in a drier soil climatic region: the Missouri Coteau in south-central Sask.

Information Sharing:

F. Mensah. 2000. Conversion of Annually Cropped Land to Grasses: Effect on Soil Carbon. MSc. Thesis, Dept. of Soil Science, University of Saskatchewan. 130 pp.

J.J. Schoenau and S.S. Malhi 2001. Managing Fertility in Forages. Invited presentation to Meacham Hills Forage Club. February 12, 2001, Meacham, Sask.

J.J. Schoenau and S.S. Malhi. 2001. Conversion of Annually Cropped Marginal Land to Perennial Forage Increases Soil Organic Matter and Quality. Agri-Food Innovation Fund Newsletter for North-eastern Saskatchewan.

J.J. Schoenau. 2001. Understanding Nutrient Cycling and Its Relationship to Climate Change Issues. Invited Presentation at Soils and Crops Improvement Association of Nova Scotia Annual Conference, Feb. 20 and 21, 2001, Truro, Nova Scotia.

J.J. Schoenau, F. Mensah and S.S. Malhi. 2000. Conversion of Cultivated Lands to Grasses: Soil Carbon and Quality Issues. Saskatchewan Agriculture and Food Extension Update: December 14, 2000, Saskatoon, Sask.

F. Mensah, J.J. Schoenau, and S.S. Malhi. 2000. Conversion of annual cropped land to grasses. Agriculture Greenhouse Gas and Climate Change Workshop, Dec. 11 and 12, 2000, Saskatoon Inn, Saskatoon.

J. Nelson, J.J. Schoenau and S.S. Malhi. 2000. A comparison of carbon in the wetland fringe of grass versus cultivated systems. Agriculture Greenhouse Gas and Climate Change Workshop, Dec. 11 and 12, 2000, Saskatoon Inn, Saskatoon.

J.J. Schoenau, F. Mensah and S.S. Malhi. 2000. Conversion of Marginal Lands to Forages: Effects on Soil quality and fertilzer needs. Invited presentation at Crop Management Forum, Canadian Association of Agri-Retailers, Nov. 14, 2000, Travelodge Hotel, Saskatoon, Sk.

J.J. Schoenau, F. Mensah, and S.S. Malhi. 2001. Potential for Carbon Sequestration and Soil Quality Improvement with Forages. Proceedings of Soils and Crops 2001, University of Saskatchewan, University Extension Press.

F. Mensah, J.J. Schoenau and S.S. Malhi. 2000. Conversion of Land to Grasses: Effects on Soil Carbon. Proceedings of Canadian Society of Soil Science Annual Meetings, July 15 – 19th, Winnipeg, MB. pp. 81.

F. Mensah, J.J. Schoenau, S.S. Mahli and P. Curry. 2000. Conversion of Annual Cropped Lands to Grasses: Effect on Soil Carbon. Proceedings of Soils and Crops 2000, University of Saskatchewan, University Extension Division

F. Mensah. 2000. Soil improvement and carbon sequestration with forages. Soil Science Dept. Graduate Student Seminar, March 13, 2000.

Participation, presentation and discussion of preliminary results at the "Carbon Sequestration in Wetlands Workshop" Winnipeg, Manitoba, April 19 and 20, 1999.

Project Success: As indicated in the information sharing section, there is demand for information on the results of this project. Information from this study has also been provided to several policy study groups, including the Center for Studies in Agriculture, Law and the Environment, as the findings have implications in the role of agricultural soils and land use management in greenhouse gas emissions reductions.

U of S Personnel Involved:

Mr. Frederick Mensah, MSc student, completed.

N. Howse, casual technical help

Dr. Renato de Freitas, research associate

Equipment: None

Project Photos: Provided in previous progress reports.

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Project Public Information Materials: As described in information sharing section above.

Expense Statement: See statement prepared by University of Saskatchewan Financial Reporting Services.